Past and Current Surveys for Metal-Poor Stars

Timothy C. Beers
Department of Physics & Astronomy
and
JINA: Joint Institute for Nuclear Astrophysics
Michigan State University
Historical Background

• The importance of metal-poor stars for constraining the nature of the first generations of objects to form in the Universe has long been recognized.

• At this meeting, so far, emphasis has been placed on examination of the distribution of metallicities ([Fe/H]) in the halo.

• The distribution of metallicities ([Fe/H]) in stars of the halo has been intensively studied for over 25 years.
  – Especially since recognized that halo contains stars with [Fe/H] < -2.5 (lowest metallicity globular clusters).
  – Long limited by small number statistics, in particular for [Fe/H] < -2.0.
Following this Theme -- Remaining Questions Concerning the halo MDF

• What is the shape of the low-metallicity “tail” of the halo MDF? Is it continuous?

• What is the low-metallicity cutoff of the tail of the halo MDF?

• Is the halo MDF constant throughout the halo, e.g., with distance?

• Can the details of the halo MDF be accounted for by contemporary galaxy assembly models?
Answers to the Above Require…

• Substantially larger samples of low metallicity stars, ideally chosen without kinematic bias, especially with $[\text{Fe/H}] < -2.0$

• Measurements of distances, radial velocities, and where possible, proper motions, for these same samples
Summary of Present Progress

• HK Survey (formerly known as Preston-Shectman survey)
  – Stars selected visually from objective-prism plates
  – Follow-up UBV photometry and 1-2 Å spectroscopy

• Hamburg/ESO Survey (HES)
  – Stars automatically selected from objective-prism plates
  – Follow-up BVRI photometry and 1-2 Å spectroscopy

• Stellar Component of Sloan Digital Sky Survey
  – Public data (through DR5) includes some 150,000 stars with available ugriz photometry and 2.5 Å resolution spectroscopy over 3800-9000 Å
  – Many stars included for use in calibration of reddening and spectrophotometry of the SDSS main survey, which samples the low-metallicity turnoff of the halo
Observational Follow-Up
HK, HES, DR5

<table>
<thead>
<tr>
<th>Survey</th>
<th>Spectra</th>
<th>Unique</th>
<th>UBV</th>
<th>J-K</th>
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<tbody>
<tr>
<td>HK</td>
<td>14488</td>
<td>11212</td>
<td>4944</td>
<td>10438</td>
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<tr>
<td>HES</td>
<td>7465</td>
<td>6212</td>
<td>812</td>
<td>5078</td>
</tr>
<tr>
<td>DR5</td>
<td>~150000</td>
<td>~135000</td>
<td>...</td>
<td>...</td>
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</tbody>
</table>

Note: Roughly 40% of HK + HES spectra obtained with UK Schmidt + 6dF
Determination of Metallicities for HK and HES Targets

• Application of the Beers et al. (1999) calibration of KP vs. (B-V)o – where available, or based on estimated (B-V)o from HP2 (Balmer line index), for warmer stars

• Application of newly developed Artificial Neural Network calibration of KP vs. (J-K)o, for cooler stars

• For clearly carbon-enhanced stars, application of Rossi et al. (2005) calibration based on KP vs. (J-K)o for stars with measured [Fe/H] and [C/Fe]
Preliminary “As Observed” MDF: HK Survey

N = 6065
<-2 = 1211
<-3 = 144
Preliminary “As Observed” MDF: Hamburg/ESO Survey

N = 3604
< -2 = 1545
< -3 = 236
Comparison of MDFs for HK Survey and HES
Preliminary “As Observed” MDF: HK + HES Surveys

N = 9669
< -2 = 2756
< -3 = 380
Preliminary “As Observed” MDF: HK + HES Surveys (Close Up / [C/Fe] > +1.0 removed)

< -2 = 2473
< -3 = 237
What Remains to be Accomplished?

• Detailed checking of individual stars
• Additional UBV and/or BVRI photometry
• Searches for available proper motions
• Checking/averaging of radial velocities
• Validation of $[\text{Fe/H}] < -2.0$ spectra with improved S/N observations
SEGUE: The Sloan Extension for Galactic Understanding and Exploration

• Fully funded (Sloan Foundation / NSF / Partners) for operation through July 2008

• Use existing SDSS hardware and software to obtain:
  – 3500 square degrees of additional ugriz imaging at lower latitudes
  – Medium-resolution spectroscopy of 250,000 “optimally selected” stars in the thick disk and halo of the Galaxy
    • 200 “spectroscopic plate” pairs of 45 / 135 min exposures
    • Objects selected to populate distances from 1 to 100 kpc
SEGUE observing plan and status as of June 2006

- Planned SEGUE scan (3500 sq deg)
- Sgr stream planned scan
- Declination = -20 degrees
- Completed SEGUE imaging
- Planned SEGUE grid pointings (200)
- Planned targeted SEGUE pointings (60)
- Completed SEGUE plate pointing
SEGUE uses stellar probes of increasing absolute brightness to probe increasing distances in the disk, thick disk and Milky Way halo.

Other spectroscopic surveys will not probe as deep, for instance, Blue Horizontal Branch Stars (BHBs) from a survey with V< 12 are from a volume within 1.5 kpc of the sun.
The SDSS Spectrograph
Plug Plate

Identification of targets on the sky

A prepped and drilled plate\textsuperscript{17}
A Cartoon Version

SDSS Spectra
SEGUE Targets per Pointing
(1200 Stars)

Based on $u griz$ color selections / split into two plates at
“bright”: $14.0 < g < 18.0$ ; “faint”: $18.0 < g < 20.5$

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantity</th>
<th>Classification</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>WD</td>
<td>25</td>
<td>KII</td>
<td>95</td>
</tr>
<tr>
<td>Cool WD</td>
<td>10</td>
<td>LOW [Fe/H]</td>
<td>150</td>
</tr>
<tr>
<td>A/BHB</td>
<td>50</td>
<td>MS+WD</td>
<td>~5</td>
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<tr>
<td>MP-MSTO</td>
<td>200</td>
<td>high-PM</td>
<td>25-30</td>
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<tr>
<td>F/GV</td>
<td>50</td>
<td>sdM</td>
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<tr>
<td>GV</td>
<td>375</td>
<td>AGB</td>
<td>10</td>
</tr>
<tr>
<td>KV</td>
<td>95</td>
<td>L,T</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>
Distribution of [Fe/H] for R-process Enhanced Stars from HERES
The SDSS/SEGUE Spectroscopic Pipeline -- Determination of Atmospheric Parameters

• 6 methods for abundance determination based on line indices or Spectral Matching
  – Call K (KP) vs. predicted (B-V)o [(g-r)o]
  – Autocorrelation Function vs. predicted (B-V)o [(g-r)o]
  – Ca Triplet vs. predicted (B-V)o [(g-r)o]
  – Call K + metallic line regions + ugriz
  – Spectral/Photometric matching (ugriz)
  – Artificial Neural Network analysis (spectra only)

• 5 methods for log g determination
  – CaI 4227 vs. predicted (B-V)o
  – MgH vs. predicted (B-V)o
  – MgH (and other gravity sensity features) vs. ugriz
  – Spectral/Photometric matching
  – ANN

• 3 methods for Teff determination
  – Balmer lines + ugriz
  – Spectra/Photometric Matching
  – ANN
An Example of Spectral Variation over Parameter Space (Allende Prieto et al. 2006)
Actually, this is a **HIGHLY abbreviated version** of the VAC, which will also include additional photometry, astrometry, spectral classification, distances, spectral indices, and notes on peculiarities of individual stars.
SEGUE Sample Spectra – F Turnoff Stars

- $T_{\text{eff}} = 6866$
  - $\log(g) = 4.19$
  - $[\text{Fe/H}] = -2.00$

- $T_{\text{eff}} = 6163$
  - $\log(g) = 3.37$
  - $[\text{Fe/H}] = -2.37$

- $T_{\text{eff}} = 6438$
  - $\log(g) = 4.66$
  - $[\text{Fe/H}] = -2.69$

- $T_{\text{eff}} = 6266$
  - $\log(g) = 3.08$
  - $[\text{Fe/H}] = -2.34$

- $T_{\text{eff}} = 6591$
  - $\log(g) = 3.54$
  - $[\text{Fe/H}] = -0.21$

- $T_{\text{eff}} = 6026$
  - $\log(g) = 3.16$
  - $[\text{Fe/H}] = -3.08$

Wavelength [Å]
SEGUE Sample Spectra – G Dwarf Stars

- $T_{\text{eff}} = 5776$, $\log(g) = 4.35$, $[\text{Fe/H}] = -0.35$
- $T_{\text{eff}} = 5443$, $\log(g) = 4.04$, $[\text{Fe/H}] = -0.56$
- $T_{\text{eff}} = 5638$, $\log(g) = 4.62$, $[\text{Fe/H}] = -0.37$
- $T_{\text{eff}} = 5527$, $\log(g) = 2.98$, $[\text{Fe/H}] = -0.63$
- $T_{\text{eff}} = 5510$, $\log(g) = 4.42$, $[\text{Fe/H}] = -0.30$
- $T_{\text{eff}} = 5521$, $\log(g) = 3.54$, $[\text{Fe/H}] = -1.68$

Wavelength [Å]
SEGUE Sample Spectra – Low Metallicity Stars
SEGUE Sample Spectra – Carbon Enhanced Metal-Poor Stars

\[ \begin{align*}
\tau_{\text{eff}} &= 6886 \\
\log(g) &= 3.59 \\
[\text{Fe/H}] &= -2.38 \\
\tau_{\text{eff}} &= 6860 \\
\log(g) &= 2.97 \\
[\text{Fe/H}] &= -2.49 \\
\tau_{\text{eff}} &= 6928 \\
\log(g) &= 3.12 \\
[\text{Fe/H}] &= -2.00 \\
\tau_{\text{eff}} &= 5455 \\
\log(g) &= 3.11 \\
[\text{Fe/H}] &= -2.19 \\
\tau_{\text{eff}} &= 4886 \\
\log(g) &= 3.48 \\
[\text{Fe/H}] &= -2.09 \\
\tau_{\text{eff}} &= 4746 \\
\log(g) &= 2.51 \\
[\text{Fe/H}] &= -2.01
\end{align*} \]
Likely Numbers of Detected MP Stars from SEGUE

- Actual numbers will depend on the shape of the halo Metallicity Distribution Function

- $[\text{Fe/H}] < -2.0 \quad \sim 20,000 \ (\text{VMP})$
- $[\text{Fe/H}] < -3.0 \quad \sim 2,000 \ (\text{EMP})$
- $[\text{Fe/H}] < -4.0 \quad \sim 200 \ ? \ (\text{UMP})$
- $[\text{Fe/H}] < -5.0 \quad \sim 20 \ ? \ (\text{HMP})$
- $[\text{Fe/H}] < -6.0 \quad \sim 2 \ ? \ (\text{MMP})$
The Plan of Attack

• **SEGUE** identification of bright MP giants with [Fe/H] < -2.0
• Brightest 2000-3000 taken to HET, etc., for “snapshot” high-resolution spectroscopy
• Most interesting (e.g., r-process / s-process-enhanced) stars thus identified taken to, e.g., VLT/Subaru/Keck/LBT, etc. for higher S/N determinations of elemental abundance patterns
• Construction of astrophysically-consistent scenarios to account for patterns and frequency of n-capture (and other) abundance patterns
• Note: Within 5 years, expect to be able to obtain medium-res data for many tens of millions of individual stars (LAMOST / SDSS-III ?) High-res data for many of the most interesting stars discovered